The Feasibility of Alternative Fuels and Technologies: An Assessment of Addison County Transit Resources' Current and Future Options

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Executive Summary and Recommendations

Rising oil prices, uncertain future reliability of oil reserves and the negative environmental impact of greenhouse gases (GHGs) have necessitated a transition to alternative fuels and technologies in all segments of the economy. Addison County Transit Resources (ACTR) is a non-profit transportation agency based in Middlebury, Vermont whose mission is to "*enhance the economic, social, and environmental health of the region by providing public transportation services that are safe, reliable, accessible, and affordable for everyone*" (Addison County Transit Resources 2008). As a rural transportation provider with ridership levels lower than more urban areas, employing the most environmentally sustainable technology is especially important to ACTR in accomplishing its mission. To work toward this goal, ACTR partnered with the Middlebury College Environmental Studies Senior Seminar (ES 401) in the spring of 2008 to evaluate alternative forms of fuels and technologies for its bus fleet. As students in the seminar, we researched five current and potential fuels and technologies and compared their local feasibilities. We compiled this report to serve as a decision-making tool for ACTR to use in choosing alternative fuels and technologies when purchasing new buses.

Alternative fuels and technologies considered in this report include hybrid electric and plug-in hybrid electric vehicles, biodiesel, ethanol, compressed natural gas (CNG), and hydrogen fuel cells. In this analysis, we evaluated many factors in the life cycles of the different fuels and technologies. It is difficult to predict exactly how well each will perform in the future, but using the data currently available, we were able to propose the following recommendations for the near term:

1. We recommend the immediate utilization of hybrid electric vehicles because a) the technology is readily available, b) no additional infrastructure is needed, and c) emissions reductions are significant. While vehicle prices are slightly greater than those of conventional diesel buses, the increased efficiency of the vehicle reduces operating costs.
2. Although biofuels were often cited in the past as ideal solutions to end dependence on oil and reduce greenhouse gases, recently published reports demonstrate that substantial social and environmental costs are associated with growing biofuel crops. Therefore, we recommend that ACTR discontinue its use of conventional biodiesel and revert to diesel in its current bus fleet until more socially responsible options are available.
3. We recommend that ACTR pursue biodiesel from locally-grown feedstocks through partnerships with local farmers and community organizations. This is a more sustainable option than conventional biodiesel and also contributes to the local economy.
4. If Vermont develops efficient technology for developing biofuels such as algae-derived biodiesel or cellulosic ethanol, ACTR should re-evaluate their feasibility in the future.
5. If Vermont develops CNG or hydrogen fuel cell transmission and distribution infrastructure, ACTR should re-evaluate the potential for CNG and hydrogen fuel cell use in the future.

Table 1. A Comparison of Five Fuels/Technologies for Addison County Transit Resources.

Alternative Fuel Vehicles Summary Chart

Key: Major Benefits (green); Minor Drawbacks (yellow); Major Drawbacks (red); Negligible change as compared to diesel (white)

	Hydrogen Fuel Cell	Compressed Natural Gas	Hybrid-Electric	Biodiesel	Ethanol
Bus Costs	Over $2 million price premium	$45,000 premium over standard	$200,000 price premium (with incentives and subsidies, only $20,000 premium)	No price premium	$17,000-$45,000 price premium
Maintenance Costs	Higher than diesel	Higher than diesel	Less than diesel	Similar to diesel	Higher than diesel
Fuel Costs[a]	$4.46 GGE	$2.33 GGE $2.60 DGE	Fuel prices: $3.21/gallon (gasoline), $3.60/gallon (diesel), but reduced fuel usage lowers cost	B5: $2.988 GGE, $3.33 DGE B20: $3.19 GGE, $3.56 DGE B100: $3.99 GGE, $4.45 DGE	$5.69 GGE $6.35 DGE
Criteria Pollutants	No emissions	Significant pollutant reduction	Emission reductions through greater efficiency	Moderate emissions reductions	Moderate emissions reductions, Significant increases in NO_X
LCA of GHG	Depends on hydrogen production process[b]	Equivalent to diesel	Greater efficiency reduces emissions	Significant increase over diesel	Significant increase over gasoline
Noise	Most quiet	Much quieter	Much quieter	Same as diesel	Same as diesel
Infrastructure	Significant capital investment necessary to develop infrastructure	Significant capital investment necessary to develop infrastructure	Requires no infrastructural additions	Requires no infrastructural additions	Infrastructure development necessary
Driving Conditions	No limitations based on climate	Efficiency decreases in cold weather	Battery efficiency may decrease in very cold weather	Efficiency decreases in cold weather	Similar to petroleum-based fuels
Social Costs	No major impacts	No major impacts	No major impacts	Major Costs (higher food prices, displaced ag land, high subsidies, negative env. impact)	Major Costs (higher food prices, displaced ag land, high subsidies, and negative env. impact)
Current Recommendations	Still 10-15 years away from economic and infrastructural feasibility	Need infrastructural developments in transmission, distribution, and fill stations to be feasible	Requires no additional infrastructure and provides greater economic efficiency and environmental benefits	The environmental and social costs of non-local biodiesel negate its availability and emission reductions	Not sustainable due to high environmental and social costs and lack of local refueling infrastructure
Future Potential	Fuel-cell and hydrogen blend fuels have potential to reduce emissions with continued government support	If CNG infrastructure improves, ACTR should reconsider CNG buses	Plug-in hybrids and more efficient technology will develop over time at lower cost	Production from algae or waste grease, and local sources will aid environmental and social sustainability	Subsidies encourage switch to more environmentally friendly and economically efficient cellulosic fuels

[a] New England average for all fuels (excluding hydrogen) in Gasoline Gallon Equivalent (GGE) and Diesel Gallon Equivalent (DGE), January 2008

[b] If produced from renewable or low pollutant energy sources, total GHG emissions are near zero, however production from coal leads to significant increases in GHG emissions

Summary Comparison Chart: This chart provides a comprehensive breakdown of several crucial components for each fuel and technology investigated in this report. All alternative fuel and technology vehicles excluding hybrid electric vehicles have major limitations, indicated in red.

Methodology

The goal of this report is to provide reference information for ACTR to use while choosing new fuels and technologies for its bus fleet. It is structured so that ACTR can have easy access to both a summary of our overall recommendations and also more comprehensive information on each fuel or technology. An easy-to-read, side-by-side comparison of the fuels and technologies is conveniently located in the beginning of the report. The middle section contains a short summary of each of the fuels and technologies, as well as in-depth research on each. The end of the report contains the references from which we derived the information. The Appendix provides information on specific hybrid electric bus manufacturers to provide ACTR with a starting point if it chooses to pursue this technology.

The chosen fuels and technologies represent the most familiar current and future options for transportation in the United States. All of the fuels or technologies are either used as demonstrations or are currently in use by various transportation agencies. We used the most current information we could find to determine the feasibility of each fuel or technology in Vermont. The amount of available research differs for each fuel/technology, making direct comparisons difficult. For example, a significant amount of biodiesel and ethanol research focuses on the source (or feedstocks) of the fuels; most hydrogen fuel cell research focuses on the state of the technology; and the majority of compressed natural gas research focuses on infrastructure. The available data, therefore, differ in terms of the units of measure and even the factors included in feasibility studies. Also, some of the fuels and technologies are more easily compared to gasoline (i.e.,

hydrogen fuel cells and ethanol) and others are more easily compared to diesel (i.e., biodiesel), simply because of differences in fuel properties and engine compatibility.

One way to overcome the disparity in available information is to compare the fuels and technologies using a life cycle analysis (LCA). A LCA examines the environmental effects of the fuel or technology from its production through its use and disposal. This includes everything from the extraction, processing, and conversion of a fuel to its transportation and combustion. Today, many LCAs are reported in terms of the amount of GHGs emitted into the atmosphere during the lifetime of the fuel.

Although LCAs are generally a good tool for comparison, problems are created when different researchers include different components in the LCA. Other difficulties are that technologies are constantly changing, there is uncertainty associated with assumptions made, and many fuels and technologies have multiple production techniques. For example, some biofuel LCAs examine the GHG emissions caused by land use change while others do not, and the LCA of hydrogen fuel cells strongly depends on the source of the power which provides the energy used in making the fuel cells.

These potential uncertainties and biases need to be considered when reviewing reports regarding any current or future technology. Throughout our research, we examined many studies and deduced what we perceived to be a fair estimate of the environmental and social impacts—and the economic feasibility—of each of the fuels and technologies, thus forming our recommendations to ACTR.

Terms Used in this Report

alternative fuel vehicle (AFV): motor vehicle that is run on fuels other than gasoline or diesel

carbon dioxide (CO_2): greenhouse gas caused by the combustion of carbon

carbon dioxide equivalent (CO_2e): unit for comparison between different greenhouse gases; one unit provides the equivalent global warming potential of one metric ton of carbon emissions

carbon monoxide (CO): odorless, poisonous gas that is the product of the incomplete combustion of carbon

criteria pollutants: air pollutants for which standards for safe exposure were originally set by the Clean Air Act of 1970 and subsequently by the EPA, which include SO_x, NO_x, PM, CO, ozone, and lead

diesel: petroleum fuel that is heavier, less refined, and generally more polluting than gasoline, but also contains more energy per gallon than gasoline

diesel gallon equivalent (DGE): amount of alternative fuel needed to equal the energy in one gallon of petroleum diesel

gasoline gallon equivalent (GGE): amount of fuel needed to equal the amount of energy in one gallon of gasoline

greenhouse gas (GHG): any gas that absorbs the infrared radiation in the atmosphere and contributes to global warming

internal combustion engine (ICE): standard engine in which the combustion of fuel and an oxidizer (typically air) occurs in a combustion chamber

life cycle analysis (LCA): comprehensive examination of the environmental and economic effects of a product or fuel from the production to the combustion, often set in terms of CO_2e emissions

lithium-ion battery (Li-ion): a type of rechargeable battery in which a lithium ion moves between the anode and cathode

methane (CH_4): odorless greenhouse gas created by the decomposition of organic matter; the main component of natural gas

nitrous oxides (NO_x): greenhouse gases created during combustion and released from soil containing agricultural fertilizers; contributes to ground level ozone, acid rain, and global warming

particulate matter (PM): small liquid or solid particles suspended in air that are created by the combustion of fuels and are linked to heart and respiratory disease

sulfur oxides (SO_x): gases caused by the combustion of sulfur, which is found in petroleum products, and which is a main cause of acid rain

Costs: The batteries do not have any operating costs and the fuel for these vehicles is diesel, which is currently hovering around $4.50 per gallon in New England.

Bus Costs: The average price of a 40-foot hybrid electric bus is approximately $450,000 to $550,000. A conventional diesel bus is approximately $280,000 to $300,000. However, the price differential for hybrid electrics can be offset by various federal incentives and grant programs. We have no data on the cost of the cutaway bus.

Maintenance: Hybrid electric buses have lower maintenance costs than conventional diesel buses due to reduced stress and maintenance on certain mechanical components, specifically brake linings. This reduction in stress should extend brake life by 50 to 100%. Also, the electric drive train has fewer parts and, therefore, requires less maintenance than a traditional transmission system.

Infrastructure: Because the vehicles only require diesel, the infrastructure for hybrid electric buses exists in Vermont.

Environment: Hybrid electric buses are estimated to cut all emissions by as much as 75% when compared to conventional diesel buses. Nitrogen oxide (NO_x) emissions for diesel hybrid electric buses are 30 to 40% lower than conventional diesel vehicles. Additionally, diesel hybrid buses emit the lowest carbon monoxide (CO) emissions of any of the buses tested including compressed natural gas (CNG) and diesel.

Future Outlook: Plug-in hybrid buses have great potential for the future once the technology fully develops and price comes down. The infrastructure for conventional hybrid electric buses is currently in place.

Recommendations: We recommend that ACTR purchase hybrid electric buses because they are the most environmentally-friendly of the commercially available technologies. Also, although all of the necessary elements are already in place, even more progress (economic, infrastructure, etc.) will be made as a result of mass implementation. For more information on purchasing hybrid electric buses, specific technologies, and funding opportunities, please see Appendix A.

Background

The three technologies that fall under the category of hybrid vehicles and will be presented in this report include hybrid electric vehicles (HEVs – to be distinguished from hybrid electric buses which is a narrower category), plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs). Hybrid technology is improving daily and is one of the most popular options available for passenger cars, commercial vehicles, and public transit vehicles.

Present-day HEVs have both an internal combustion engine (ICE) and an electric motor. The electric motor receives a charge from a battery, which provides power through a chemical reaction. The battery is continuously recharged by a generator that is driven by the ICE (National Renewable Energy Laboratory 2008). In a conventional vehicle, energy from deceleration dissipates and is wasted. In hybrid designs, regenerative braking systems capture, store, and convert the energy to electricity to propel the vehicle.

The most common engine in a HEV is a parallel design in which all components are connected directly to the vehicle's wheels. The primary engine is used for regular driving, and the electric motor brings additional power into the system for hill climbs or acceleration (National Renewable Energy Laboratory 2008). Parallel designs are also often used in hybrid electric buses.

Hybrid electric bus deployment has grown tremendously in recent years. In 2006, more than 900 hybrid electric buses were employed in regular service by more than 40 transit agencies in North America. Some of the largest fleets in the United States include New York City's fleet of 325 buses, and King County in Washington which operates 214

parallel hybrid electric buses. At that time, New York City had ordered an additional 500 diesel electric buses, and Washington had ordered 100 additional diesel electric buses (Ranganathan 2007).

The second technology, PHEV, is still in development; it is very similar to the HEV, except that it has a larger battery so is less reliant on its gasoline or diesel engine. PHEVs are recharged by plugging into the grid and can be powered for longer distances than HEVs solely by the stored electricity (United States National Department of Energy 2007).

EVs are a technology that has been available in the past but is not currently widely utilized. EVs are propelled only by an electric motor (or motors) powered by rechargeable battery packs (United States Environmental Protection Agency 2008). They can be recharged by plugging directly into the electric grid or at EV recharging stations.

As shown in Figure 1, the batteries for the three vehicles have different levels of reliance. The EV needs the most powerful battery to power the vehicle for sufficient distances; the PHEV needs the second largest because it can still rely on gasoline. Finally, the HEV is least reliant on its battery, which renders it the least independent from traditional fuel sources.

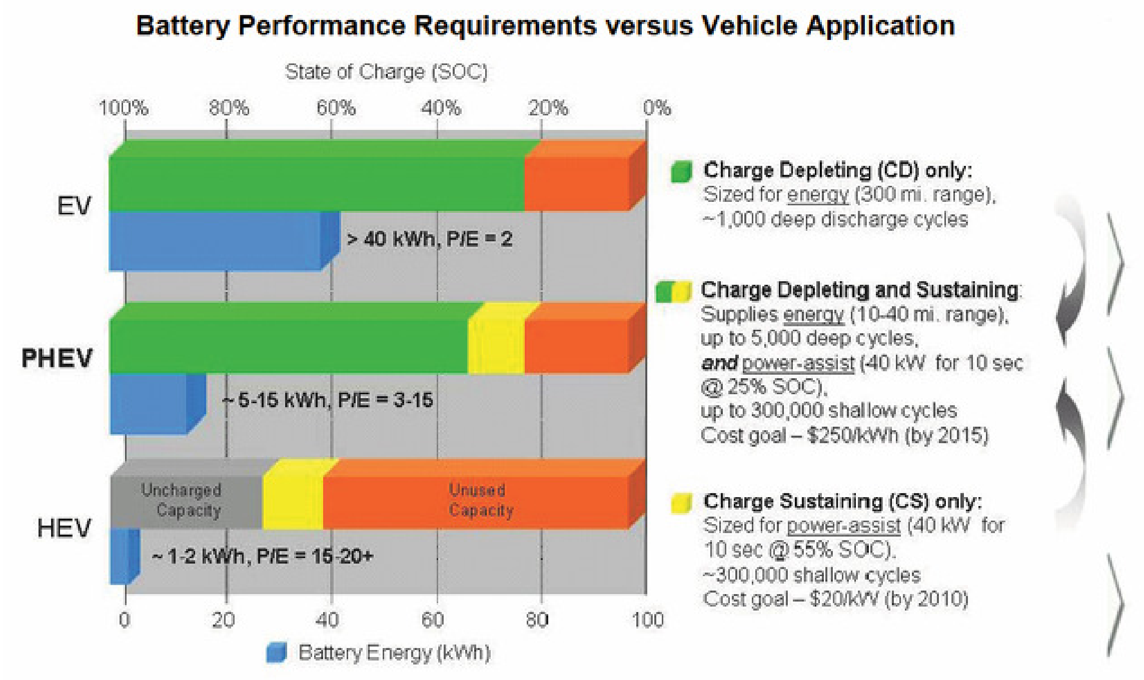

Figure 1. Difference in batteries needed for each of the three technologies (Green Car Congress 2007).

Sourcing

HEVs are available as transit buses. The infrastructure for diesel is currently in place and the battery charging (regenerative breaking) technology has been implemented. The three major manufacturers of all types of hybrid systems are General Motors (GM) with its Allison Transmission products (Allison EP50 and EP40), BAE Systems, and ISE Corporation. GM's hybrid electric buses are currently in service all across the United States operating in 25 cities including Seattle, Orange County, Philadelphia, Houston, Tampa, and Albuquerque. In addition, Yosemite National Park uses GM hybrid electric buses (General Motors 2005). The GM Allison EP50 parallel hybrid electric propulsion system has a unit with two motors capable of producing 75 kW of continuous power and up to 150 kW of power at full potential. This system combines the power of the engine and the electric motor and provides up to a 90% reduction in certain emissions over a

conventional diesel system in a transit bus application. The system becomes even more efficient with regenerative braking (Chandler 2006).

BAE Systems (the combination of British Aerospace (BAE) and Marconi Electronic Systems (MES)) produces the Orion VII HybriDrive® propulsion system, which is quite suitable for transit organizations. It has very similar benefits as the GM system. ISE Corporation also has a very similar technology in its ThunderVolt® Hybrid Drive Systems which is currently used by New Jersey Transit.

The majority of hybrid buses in current service are 40-foot buses. However, for ACTR's purposes, all of these systems can be utilized in smaller buses. For example, New Flyer of America, Inc. produces 30-foot hybrid electric transit buses. Ebus produces 22-foot shuttle buses (Ranganathan 2007). Please see Appendix A for further information about the all of these suppliers of hybrid electric buses and their components.

Practicality

Infrastructure

Hybrid electric buses are currently very practical for Vermont because the infrastructure for diesel is present. In addition, the hybrid electric buses can be purchased by ACTR and utilized immediately. The technology continues to improve, but the most recent research and technology in hybrid electric buses is currently on the market.

PHEVs have potential, but there are several barriers preventing their widespread commercialization. As is stated above, PHEVs require a larger, stronger battery so battery technology needs to be developed further and availability needs to be increased. There is a lack of domestic sources for batteries. The demand for these vehicles has yet to

reach a reliable level, and data on their operation in different climates is unpredictable or lacking; what is known is that the battery's performance and life expectancy are higher in warmer weather and are unpredictable in cold weather. However, there are cases documenting their successful operation in cold temperatures (up to -50 ^{o}F). There are issues with the mass and volume of the hybrid component of the vehicle and the cost and safety of these vehicles (United States National Department of Energy 2007). Right now, the battery packs take up a lot of space, which decreases storage space and makes the vehicles heavier.

Central Vermont Public Service purchased two plug-in hybrid vehicles in June of 2007 and recently purchased a third that they donated to the University of Vermont to determine the feasibility of plugging into Vermont's electric grid. Their results have been promising and indicate that PHEVs could support the energy infrastructure of the state (Letendre, personal communication 2008).

The conversion of an HEV automobile to a PHEV currently costs around $10,000, although detailed information about conversion of hybrid electric buses to plug-in hybrid electric buses is not readily available. Also, there are currently no mass-marketed electric automobiles or buses, and the existing vehicles face a variety of challenges – particularly battery related challenges.

Costs

Cost premiums for hybrid electric buses can be offset by fuel cost savings and tax incentives (see Funding Opportunities below). Their performance and safety ratings are comparable to conventional vehicles (United States National Department of Energy

2007). Also, batteries are currently very expensive, and there are very few high-volume manufacturing facilities for high-energy automotive batteries. This factor drives the cost gap between highly efficient batteries and those currently in circulation. If this industry scales up, the costs will immediately come down.

With the current system and technology, 40-foot hybrid electric buses are between $170,000 and $250,000 more expensive than conventional diesel buses. The price variation in hybrids is due to the order volumes and individual specifications of transit agencies (Ranganathan 2007). We would anticipate that 22- or 28-foot buses would have a similar price premium. Upfront costs may eventually be offset depending on the amount, type, and frequency of driving, and also over what periods of time buses are in use. A year-long evaluation from the National Renewable Energy Laboratory indicated that operational costs for HEVs are 15% lower than conventional diesel buses. Similarly, King County Transit's (Seattle, WA) 60-foot articulated New Flyer buses equipped with General Motors' Allison parallel hybrid drive was found to cost less to operate and maintain than regular diesel buses (Ranganathan 2007).

Funding Opportunities

The price difference between hybrids and conventional diesel buses can be offset by federal incentives and grant programs. The federal Clean Fuels Grant Program (for a description of this program, see Appendix A) covers 90% of the incremental cost of alternative fuel buses (the difference between the cost of a hybrid bus and a conventional bus). Additionally, ACTR is eligible to receive funding from the Federal Transit Administration (Ranganathan 2007). Finally, as technology improves and the market

share for these technologies increases, the cost differential for hybrid electric buses will likely decrease.

Emissions

In general, HEVs have lower emissions than conventional vehicles of the same class because the electric motor reduces ICE use. Also, the ICE in a HEV is smaller because of the battery and turns off when not in use (i.e., while idling or coasting). There are emissions associated with the life cycle of the vehicles, taking into account the production, assembly, and disposal of the vehicles and vehicle materials as well as the source of electricity production. Battery disposal can also be detrimental to the environment.

The environmental benefits of PHEVs are most greatly affected by the source of electricity that charges its battery, and there are considerably more life cycle emissions if the electricity is produced from fossil fuels rather than from clean, renewable energy. Electricity in Vermont is primarily derived from nuclear power and hydropower, which are fairly clean sources (if the extraction of uranium, nuclear waste disposal, and construction of the nuclear plant or dam are removed from the analysis). Therefore, the electricity source is not much of a detriment when discussing emissions for PHEVs in Vermont. One study found that PHEVs "reduce GHG emissions by 32% compared to conventional vehicles, but have small reductions compared to traditional hybrids" (Samaras 2008). Even though the reductions are small, they are still present and PHEVs are less reliant on petroleum fuels than HEVs, making PHEVs a more environmentally sustainable option than HEVs.

EVs produce no direct emissions so only the electricity source and battery disposal are relevant for EVs. One study projected an average 42% reduction in carbon emissions from mileage driven on low-carbon electricity instead of gasoline (United States National Department of Energy 2007). An EV has the potential to be non-emitting during the different stages of its "life" if the electricity is produced from clean, renewable energy sources like hydropower, solar power, and wind power, or if it is produced from nuclear power plants (again disregarding nuclear waste and uranium extraction) (United States Environmental Protection Agency 2008).

Local programs exploring the technology of the future include Solectria, the Northeast Advanced Vehicle Consortium (NAVC), the United States Department of Transportation, and EVermont (the Vermont Electric Vehicle Program). They have joined forces to develop a hybrid electric version of a typical school bus. Solectria's components are currently used in buses that are between 22 and 40 feet. The program plans for the bus to be capable of operating in both a hybrid mode and a completely electric mode. While operating as a hybrid, this bus can travel hundreds of miles between fill-ups of its diesel fuel tank. While operating in its "pure electric" zero-emission mode, it can travel up to 60 miles on one charge of its lead acid battery pack (Blue Bird Electric Racing Limited 2005).

Efficiency

In a conventional vehicle, energy from deceleration dissipates and is wasted. In hybrid designs, regenerative braking systems capture, store, and convert energy to electricity to propel the vehicle, thereby decreasing even further the amount of fuel used.

To further maximize energy efficiency, some hybrids utilize ultra-capacitors, which capture the power from regenerative braking and release / re-use it for initial acceleration to prolong battery life (National Renewable Energy Laboratory 2008). A HEV has advanced control software that allows the vehicle to operate more efficiently and pollute less. Basic HEV technology increases the overall efficiency of the vehicle, thereby increasing the fuel economy and making HEVs the most efficient type of mass-marketed automobile today.

Excluding a life cycle analysis, EVs convert 75% of the chemical energy from the batteries into power to make the vehicle move. ICEs convert only 20% of the energy stored in gasoline into power to make the vehicle move (United States Environmental Protection Agency 2008). Similar to emissions, when accounting for the entire life cycle the efficiency of the vehicle depends on the electricity source.

Additionally, the way a vehicle is operated greatly affects its mileage efficiency. This is especially true with all hybrids, which are more efficient when their brake system is being engaged and contributing to the recharging of the vehicle. HEVs have the potential to operate solely on the battery for speeds up to 30 miles per hour. Therefore, city driving and routes with frequent stopping increase the fuel economy of the vehicle; this makes a considerable difference as the total miles traveled increases. The design of public transportation, regardless of whether in urban or rural communities, would help to maximize hybrid electric vehicle efficiency because of the frequent stops and therefore, the frequent use of the regenerative breaking system.

Future Outlook

Research is ongoing to improve current battery technologies. This research should improve driving range and decrease the recharging time, the necessity for battery replacement and, ultimately, weight and cost (United States Environmental Protection Agency 2008). Developing a marketable, longer lasting battery will greatly advance the PHEV technology. Most batteries in production are Nickel Metal Hydride (NiMH). However, Lithium-Ion (Li-ion) batteries are considered the front runner for the PHEV because of their higher specific energy and power (United States Department of Energy 2007). Interestingly enough, Li-ion uses low-cost and abundant materials in comparison to NiMH, but the actual end-product sells for a much higher price. A much needed research focus on developing and evaluating Li-ion battery cells, packs, and full systems to be used in HEVs is currently underway (United States Department of Energy 2007).

There are some current technological drawbacks associated with Li-ion. Li-ion batteries' ability to regenerate power through the braking system is significantly reduced at temperatures lower than -20 ºC. Even though the end-use is not the same, there is evidence with current usage patterns that Li-ion batteries used in consumer electronics are not very tolerant of abnormal conditions which include short circuits, overcharge, over-discharge, crushing, or exposure to high temperatures (United States Department of Energy 2007). All of these things could happen on a different scale if used in vehicles. Li-ion batteries still require a bit of research and development and, after their development, there is likely to be a significant lag time before costs come down. As shown in Figure 2, it could potentially take five years for battery technology to become affordable. This results in a slow process for mass commercialization providing time for

these technologies to meet resistance from other researchers or from competing technologies.

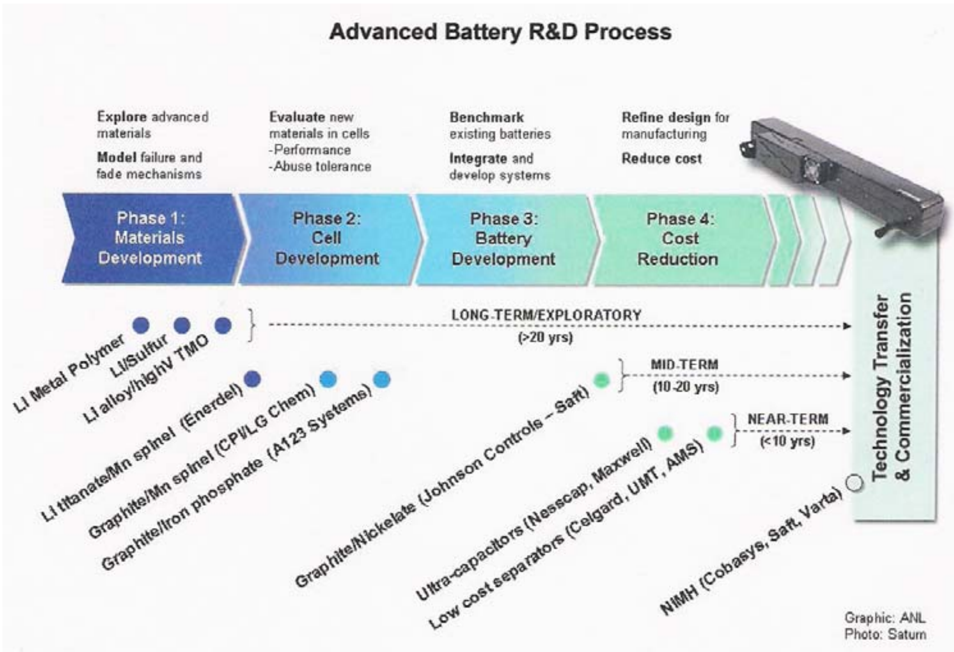

Figure 2. The process to make these more efficient technologies more economically viable (United States Department of Energy June 2007).

Another area of concern is that plugging in many PHEVs into the electric grid to recharge would overload the current generation system. The demand for electricity is generally high during the day and low at night (United States National Department of Energy 2007). A PHEV battery could be charged at night during low demand, which would not place an extra burden on the grid.

Also, PHEVs have the potential to greatly improve the nation's electrical generation and distribution system and make it more reliable. There is potential for PHEVs that are unused during periods of peak demand to be additional energy sources while plugged into the grid (known as vehicle-to-grid capabilities). PHEV drivers would charge their vehicles while demand and electricity prices are low and, when their vehicles are idle, sell electricity back to the utility when demand and prices are high (Letendre

personal communication 2008). If electricity demand reached a certain threshold, energy from PHEV batteries could help utilities avoid building additional generation capacity to meet peak demands.

If vehicle-to-grid capabilities are developed and employed, PHEVs could help make the entire system of renewable technologies more reliable. Currently, wind power generation is very intermittent and needs a back-up source of generation to ensure a steady flow of power. Wind-generated electricity could be stored in PHEV batteries while the wind is blowing and during periods of low demand. That stored power could be extracted when the wind speed decreases or when energy demand is high. A National Renewable Energy Laboratory report calculates that, if half of United States vehicles were PHEVs, wind turbine electrical generation would double (United States National Department of Energy 2007).

Recommendations

It is important for ACTR to consider purchasing HEV buses at this time. It is the most environmentally-friendly of the commercially available technologies. Also, even more progress (economic, infrastructure, etc.) will be made as a result of mass implementation. The substantial upfront cost of HEVs is offset by lower operating costs—as compared with conventional vehicles—and by rebate opportunities. Furthermore, the infrastructure supporting HEVs can easily extend to PHEVs once available, and, ultimately, EVs once the technology is ready for mass implementation. If the electricity used is derived from renewable, emission-free power sources, it may help the transportation sector to eventually become carbon neutral.

Fuel Costs: As of May 14, 2008, according to Champlain Valley Plumbing and Heating, B20 costs $4.00 per gallon. This translates to $4.04 per diesel gallon equivalent (the amount of energy in one gallon of diesel). At the pump, according to the AAA Fuel Gauge Report, diesel in Vermont costs, on average, $4.50 per gallon.

Bus Costs: Bus costs for biodiesel are equivalent to diesel bus costs.

Maintenance: The use of biodiesel does not result in any extra maintenance costs.

Infrastructure: Current diesel infrastructure can be used for biodiesel transport and storage.

Environment: The combustion of biodiesel emits less PM, SO_x, and CO, and slightly more NO_x than diesel. According to most studies, biodiesel produces 50% less GHG emissions than diesel over its life time. Multiple studies have been published in the past year that enumerate the environmental and social costs of biodiesel production from monoculture crops in the United States and globally, which include increased food prices, the destruction of rainforest to make way for biofuels crops, and the excess consumption of water.

Future Outlook: Since biodiesel can be produced from any oil-based organic material, there is potential for algae and waste-grease feedstocks. Waste-grease technology is available but is not as subsidized as food-based technology. The supply of wastes is also limited in Vermont. More research needs to be done on algae-based biodiesel in order to make the process energy-efficient. Sustainable production of biodiesel could also occur through local partnerships with Addison County farmers.

Recommendations: Because of the recently recognized social and environmental costs of biodiesel production, ACTR should discontinue its use of conventional biodiesel. In order to continue using the fuel, it should investigate partnerships with local farmers and community organizations.

Background

Biodiesel is a liquid fuel produced from oil-based organic material, such as soybean oil, canola oil, or waste animal fats. Biodiesel is made through a process called transesterification, which separates glycerin, a material generally used for soaps and solvents, from the oils in the feedstock, producing the fatty acid methyl esters that comprise biodiesel (Vermont Biofuels Association 2008). This process requires a low energy input, especially when compared to the production of ethanol (see Ethanol Section), because of the low temperatures needed for the chemical process (Childs and Bradley 2007). Biodiesel is biodegradable and non-toxic and has a lower flash point than diesel, making it less volatile (Zhang et al. 2003).

Sourcing

Biodiesel is produced from a variety of feedstocks. In the United States, the main sources are soybeans from monoculture farms based mostly in the Midwest. In Canada and Europe the main feedstock for biodiesel is canola, also called rapeseed. Palm and sunflowers can also be used. The per-acre efficiencies of each crop differ dramatically (see Figure 3). Despite their widespread use, these food-based feedstocks create numerous social and environmental issues. Converting cropland and marginal lands to biodiesel production has been shown to accelerate clearing of the Amazon rainforest and divert important fresh water supplies (Childs and Bradley 2007, Searchinger 2008). Due in part to the growing demand for biofuels, the rising worldwide population, and price speculation, the price of soybeans and wheat—in addition to corn—have risen dramatically. This creates financial strains for impoverished people in the United States and across the world (Neary 2008).

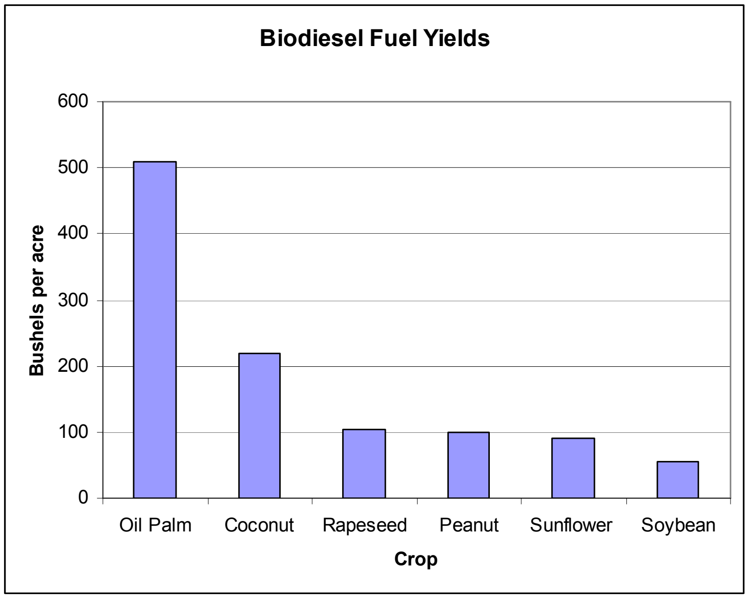

Figure 3. Per acre yields of common biodiesel crops (Childs and Bradley 2007).

Because of the large environmental and social equity problems caused by the production of food-based feedstocks, many scientists have recommended converting waste oils from cooking oil and animal fat to biodiesel. This avoids the large carbon emissions from land use change and produces energy from the byproducts of other industries (Searchinger 2008, Hill 2006). Waste oil is also cheaper than virgin vegetable oil for biodiesel manufacturers, although it does require an extra step in the production process to clean the oil. Zhang et al. (2003) found, however, that waste-based biodiesel can be economically effective even with the extra startup equipment costs. In fact, the production of soybean and canola biodiesel costs $2.98 and $3.20 per gallon, respectively, while waste biodiesel costs only $1.67/gal to produce (Jensen et al. 2007). There is much less governmental support for waste feedstocks than there is for food-based feedstocks. The Energy Policy Act of 2005 extends a tax credit of $1.00 per gallon

of agri-biodiesel and only $0.50 per gallon for waste-grease biodiesel (Office of the Biomass Program 2007). The supply of waste grease that can be used for biodiesel production both nationally and in Vermont is limited (Chisti 2007).

Algae probably has the highest potential of all biodiesel feedstocks to reduce the environmental and social costs of production. Algae produces higher yields of oil more efficiently than any of the field crops and does not necessarily impinge upon valuable agricultural land. Like all other photosynthetic organisms, algae require CO_2 in order to create energy and could potentially be used to sequester emissions from petroleum power plants or be used in conjunction with manure waste processing and methane-electric generation facilities on local farms (Levine 2008). Right now, the main problem with algae production is that the extraction of oil from the algae is energy-intensive and that the resulting biodiesel is not cost-competitive with regular diesel (Chisti 2007).

Some Vermonters believe that the production of biofuels on unused agricultural land could stimulate the local economy (Vermont Biofuels Association 2008). However, most Vermont suppliers currently receive their biodiesel from large wholesale suppliers across New England, Eastern Canada, and the Mid-Atlantic. These suppliers, in turn, buy their biodiesel from larger suppliers and production companies in the central United States and across the world.[1] BioCardel Vermont, a biodiesel production facility in Swanton, Vermont, was established in 2006. According to its website, the facility currently produces 4,000,000 gallons of biodiesel per year, but as of now, the majority of the feedstock comes from outside of the state (BioCardel 2008).

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[1] Information received through personal communication via phone calls to biodiesel dealers listed on the Vermont Biofuels website: http://www.vermontbiofuels.org/wheretobuy/wheretobuy.shtml.

Practicality

Infrastructure

Biodiesel can be easily incorporated into the oil distribution infrastructure because of its similarity to diesel. There has been little research into whether there are any long term effects on the current infrastructure from using biodiesel (Childs and Bradley 2007). Biodiesel can be blended into petroleum diesel at multiple ratios and used in standard diesel engines. The use of B100, or 100% biodiesel, may require the replacement of natural rubber and elastomer compounds in the engine, although these materials are not generally used in contemporary engines (Fulton et al. 2004).

Fuel Considerations

The main problem with biodiesel, in terms of mechanical practicality, is that it is difficult to combust in cold temperatures. A study by the Cold Flow Consortium in Minnesota has shown that the fuel needs to be kept more than 10 °C above its cloud point, the temperature at which the fuel begins to congeal, in order to combust. Since the cloud point is higher with the higher blends of biodiesel, lower blends need to be used in the winter (Cold Flow Consortium 2004). Heating implements can also be used to ensure that the fuel is above its cloud point (Fulton et al. 2004). A pilot study at Sugarbush Ski Resort in Warren, Vermont, however, reported no mechanical or operational problems with the use of B20 for grooming and snow-making during the winter months (Sugarbush Resort 2005).

Availability

In May of 2007, 148 biodiesel companies with an annual production capacity of 1.39 billion gal/yr existed in the United States. Ninety-six more were proposed, which

would add an additional 1.89 billion gal/yr. In Vermont, as of 2006, there were 17 fuel dealers (Delhagen 2006). Currently, according to the Vermont Biofuels Association, there are 33 wholesale and retail biodiesel dealers. Netaka White, Biofuels Director of the Vermont Sustainable Job Fund, estimates that, although Vermont produced less than 61,000 gallons of biodiesel in 2007, it will have the capability of producing 5-7 million gallons of "sustainably produced" biodiesel in ten years. This would cover 3% of the state's diesel demand (White, personal communication 2008).

Costs

One gallon of B100 contains 93% of the energy in one gallon of diesel and one gallon of B20 contains 99% of the energy (United States Department of Energy 2008). According to Clean Cities' January 2008 "Alternative Fuels Price Report", the average United States price of biodiesel per DGE, or the price for the amount of biodiesel that is required to equal the energy in one gallon of diesel, was $3.32, $3.43, and $4.05 for B2-5, B20, and B99-100 respectively. In comparison, the average price of diesel in the United States was $3.40 per gallon (Clean Cities Alternative Fuels Price Report 2008). Currently, diesel is $4.50 per gallon on average in Vermont (AAA 2008). Biodiesel prices have also increased almost a dollar since January. The increases in prices are parallel because of the petroleum intensive processes needed to grow and transport the feedstocks and fuel (Doornbosch and Steenblik 2007).

Emissions

Tailpipe Emissions

The combustion of biodiesel emits lower amounts of particulate matter, carbon monoxide, and hydrocarbons but greater amounts of nitrogen oxides than the combustion of diesel (A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions – Draft Technical Report 2002) (see Figure 4).

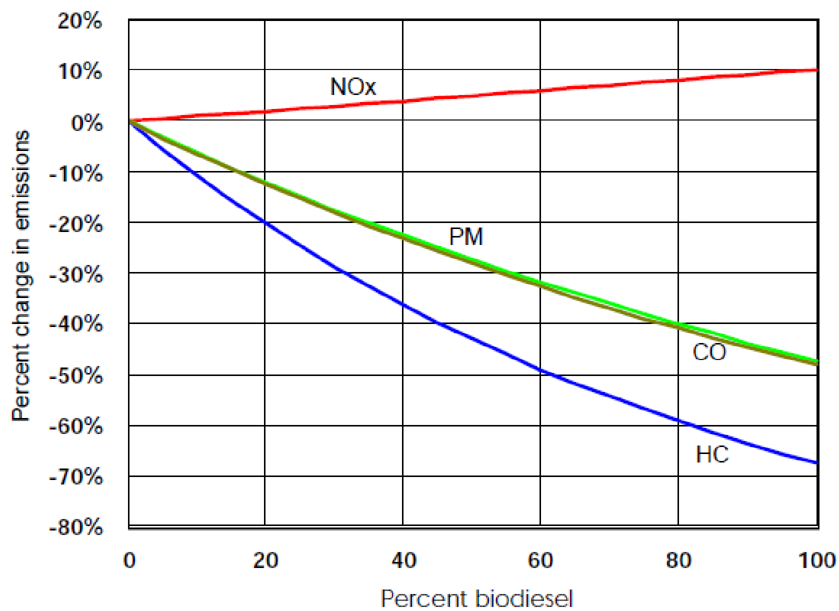

Figure 4. Biodiesel combustion emissions (EPA Exhaust Emissions Study 2002).

Life Cycle Analysis

Without accounting for emissions from land use change, studies generally show that biodiesel results in a 40-60% overall reduction in GHG emissions compared to low sulfur diesel (Samson et al. 2008). The use of different feedstocks results in differing GHG emissions reductions. Rapeseed, soybean, and waste-derived biodiesel reduce GHG emissions by 45-65%, 50%, and 62-100%, respectively (Childs and Bradley 2007, Samson et al. 2008). LCAs that incorporate GHG emissions from land use changes (i.e., conversion from dormancy to agricultural use) reveal a less positive picture. This is

especially true in equatorial zones where tropical and peatland rainforests and cerrado grasslands are being converted to palm plantations and soybean fields for use in biodiesel. In the United States, it would take approximately 50 years of biodiesel use to compensate for the CO_2 emissions caused by converting formerly-used, degraded cropland in the Midwest to monoculture crops for biofuels (Fargione et al. 2008).

Future Outlook

In order for biodiesel to achieve the goal of GHG reductions, policy changes need to be made at the national and local levels. Policies that address sustainable agriculture and land use practices and that restrict the importation of foreign energy and the exportation of food crops need to be implemented (Childs and Bradley 2007). The subsidies for food-based biodiesel also need to be lowered so that technologies for waste-grease biodiesel and algae can develop. Some European governments are already attempting to create policies that ensure the sustainable production of biodiesel (Doornbosch and Steenblik 2007).

Recommendations

If ACTR chooses to continue using biodiesel at this time, it should invest in partnerships with local farmers. Area non-profit organizations and community members are currently working toward sustainable biodiesel production and an oil extraction machine is working in Cornwall. The production of biodiesel at a local level must be restricted to lands that would not be used for food. Incentives for local sourcing could make the production of biodiesel environmentally-sound. However, if demand exceeds the local supply, the supply will be imported from elsewhere. Therefore, successful policies should limit the importation of ‘dirty’ biodiesel.

Fuel Costs: A gallon of E85 (85% ethanol, 15% gasoline) yields 37% fewer miles than a gallon of gasoline because of its lower energy content. Though price per mile depends on the vehicle's efficiency, as of May 15, 2008, national average E85 prices were $4.33 per gasoline gallon equivalent (GGE), while gasoline averaged $3.77.

Bus Costs: Regular petroleum buses can run on an E10 blend (10% ethanol, 90% petroleum) without any modifications. Flex-fuel buses that run on E85 cost between $17,000 and $34,000 more than diesel buses.

Maintenance: Operation and maintenance costs of flex-fuel buses are 75% higher than diesel buses due to ethanol fuel filters and higher replacement rates for starters, batteries, and glow plugs.

Infrastructure: Though E85 is available at 1,413 fueling stations around the country, there is no infrastructure for ethanol (E10 or E85) in Vermont. E10 can be integrated into the gasoline infrastructure; E85 requires a unique fuel line, dispenser, and metering system.

Environment: Though ethanol burns more cleanly and emits less criteria pollutants than gasoline, emissions from the land use changes required to grow corn for ethanol greatly surpass those reduced by its use. In addition, using food crops for fuel diverts these necessary food crops to the transportation industry, increasing food prices. Non-food crops used to produce cellulosic ethanol have the potential to eliminate negative effects from land use change and produce a higher yield of ethanol per acre.

Future Outlook: Heavy ethanol subsidies are currently in place, though in the last month politicians have begun to call for serious reductions in mandates. The fuel's infrastructure is limited in New England but may become more widespread in the upcoming years.

Recommendations: Even if corn ethanol becomes available in Vermont, ACTR should not utilize the fuel. Cellulosic technology may eventually become available and there are crops that could be utilized in Vermont; if this happens, ACTR could pursue a local source of cellulosic ethanol.

Background

Ethanol, also known as ethyl alcohol or grain alcohol, is made by leaching sugars from starch crops and fermenting them into alcohol. It is commonly blended with gasoline; nearly half of United States gasoline contains ethanol in a low-level blend (up to E10, or 10% ethanol and 90% gasoline) (United States Department of Energy 2008). Ethanol is also available in many places as E85, which can be used only in flex-fuel vehicles. There are two technologies for producing ethanol – conventional and cellulosic. Conventional technology is widespread and utilizes food crops such as corn or sugarcane; cellulosic technology uses the woody portion of plants found in non-food crops, and is currently being developed.

Sourcing

In the United States, 95% of conventional ethanol is derived from corn (Childs and Bradley 2007). To make conventional ethanol, the grain is first ground up to make the starches more available. Starches are converted to sugars, which are then fermented to produce CO_2 and ethanol. Once the product is distilled, it is ready to be mixed with gasoline and used in vehicles (Pahl 2007). The advantage of this process is that the high starch content in the seeds of the plant is efficiently converted into ethanol. On the other hand, this process produces a lot of waste, as only a small part of the whole plant is used in the production of the fuel. Corn produces 400 gallons of ethanol per acre (Childs and Bradley 2007).

Fertilizer, pesticide, and water use for the production of corn for ethanol is extremely high. Growing comparable amounts of soybeans for biodiesel uses 1% of the

nitrogen, 8% of the phosphorus, and 13% of the pesticides by weight than does the process of growing corn for ethanol (Hill et al. 2006). The nitrogen-rich fertilizers transported via runoff to the Mississippi River are a primary cause of what are called “dead zones” in the Gulf of Mexico – areas where phytoplankton blooms, dies, sinks to the ocean floor, and robs the water of oxygen, preventing animals from living in the area (Donner and Kucharik 2008). These dead zones have cascading effects up the food chain and can severely affect the fishing industry. Water shortages may also become an issue, as the biomass needed to produce one liter of ethanol evaporates between 1000 and 4000 liters of water (Suzuki 2008).

The use of food crops for fuel has sparked a huge debate among stakeholders in the fuel, as discussed above for the case of biodiesel. Ethanol currently consumes a fifth of United States corn production (Rosenthal and Weisman 2008). Crops that could be used to feed many are instead providing transportation for a few; one article claims that “food for fuel pits the car owners against the 2 billion poor who struggle to get enough to eat” (Leahy 2008). The increased demand and competition for agricultural land drives up corn and, subsequently, food prices, adding to the food shortage crisis. In fact, the price of corn has doubled since 2005 (Neary 2008).

Cellulosic ethanol is made from cellulose, hemicellulose, or lignin, which constitute the woody part of the plant, instead of using just the seeds (Pahl 2007). Feedstocks include non-food crops or non-food parts of plants, and range from corn stover (the leaves and stalks of corn), paper pulp, rice straw, and municipal solid waste to fast-growing plants like willow trees and switchgrass. The process for making cellulosic ethanol is slightly more complicated than conventional ethanol, as the complex cellulose

from the crop needs to be broken down further before the sugars can be fermented. The technology to do this energy-efficiently is not yet available on a large scale but is currently being developed. Cellulosic technology has many advantages over conventional. Using non-food crops (or non-food parts of the plant) eliminates the social issues created by using food for fuel; using marginal land that is not in use for other crops would minimize land use impacts; and cellulosic technology also generates a higher yield per acre than conventional technology. As shown in Figure 5, the yield of cellulosic ethanol from switchgrass already exceeds that of corn, with a large potential increase if technology improves.

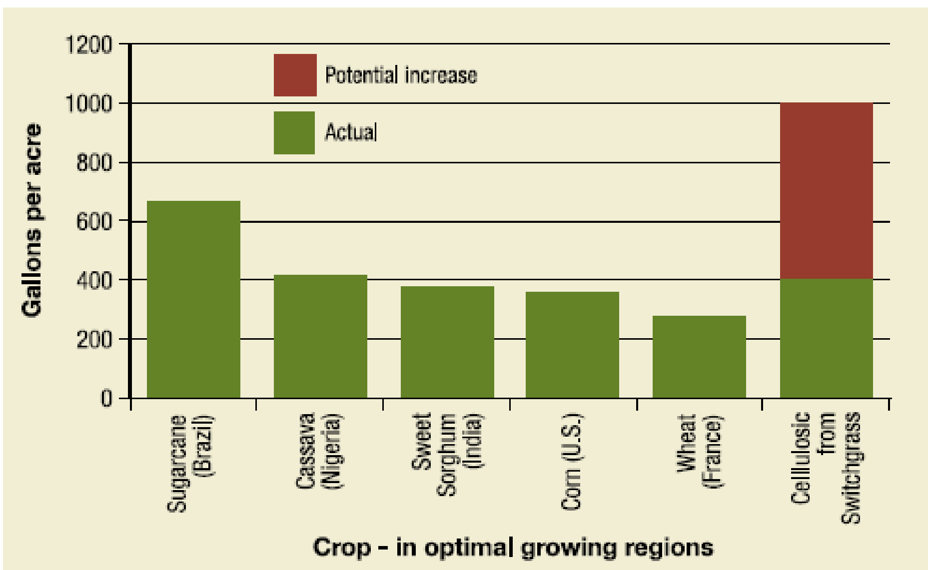

Figure 5. Ethanol fuel yields (Childs and Bradley 2007).

Practicality

Infrastructure

Ethanol is easily adapted to gasoline engines. All vehicles are capable of running on up to 10% ethanol, though a recent study by the University of Minnesota found that 20% blends could run in regular cars with no detrimental effects (Minnesota Department

of Agriculture 2008). Blends between 10% and 85% require flex-fuel vehicles that can run on gasoline or a mixture of ethanol and gasoline (United States Department of Energy 2008). These vehicles take advantage of ethanol's high octane rating (41% higher than gasoline) to manufacture a more efficient engine (Roberts 2008). Automobile companies are currently marketing this variety of vehicle heavily, though ethanol is used in these vehicles less than 1% of the time, negating the improved efficiency of the engine (Montenegro 2006). There were 6 million flex-fuel vehicles on the road in 2007 (Childs and Bradley 2007).

There is no infrastructure for ethanol in Vermont, though it is available elsewhere in the United States. Some newer petroleum equipment may be converted for use with E85, but in most cases, entirely new fueling systems need to be installed because of the difference in fuel properties. E85 pumps require a unique type of fuel line, dispenser, and metering system (United States Department of Energy 2008), which can cost up to $200,000 each (Childs and Bradley 2007). Though no change is necessary for vehicles, the use and distribution of E10 would also require investment in the transport and distribution system (Childs and Bradley 2007).

Fuel Considerations

Ethanol has other issues that can make its use more difficult or risky than petroleum. It is difficult to use in the winter; a higher gasoline-to-ethanol ratio is needed to produce enough vapor pressure to start the engine in colder temperatures (United States Department of Energy 2008). It is hydrophilic (readily attracts water) and the water it picks up can corrode and damage pipelines and storage tanks (Childs and Bradley 2007). It also makes transportation of ethanol hazardous because water degrades the

effectiveness of standard fire-fighting foam (United States Department of Transportation 2006). The highly flammable liquid is constantly transported in trucks through the Midwest, and many local firefighters “have not had training in battling ethanol fires, and the [fire] department doesn’t have the special foam to fight the blazes anyway” (Alex 2008).

Availability

About 12 billion gallons of ethanol are produced in the United States annually, and this number is rising fast (Pahl 2007). Ethanol constitutes 99% of United States biofuel production (Farrell et al. 2006). The fuel is already blended into more than half of the gasoline sold in the United States to aid complete combustion and decrease production of CO; three states have policy mandating a blend of E10 in all marketed gasoline (National Public Radio 2007). As part of the Energy Independence and Security Act of 2007, the EPA mandated the use of 36 billion gallons of renewable fuels by 2022 (American Coalition for Ethanol 2007). Devoting all corn currently grown in the United States could only supply 12% of the total gasoline demand, however (Hill et al. 2006).

Both the supply and demand sides of ethanol are being heavily incentivized. As of January 2005, a $0.51 national tax credit per gallon of ethanol used as motor fuel was put in place (Farrell et al. 2006). Between 1995 and 2005, corn (for both food and fuel) received over $50 billion in subsidies (Childs and Bradley 2007).

There are currently 1,413 E85 fueling stations in 43 states in the United States, most of which are found in the Midwest (Figure 6) (United States Department of Energy 2008). The closest fueling station to Middlebury is located 50 miles away in Lake George, New York. There is currently one farm in Vermont that is licensed to make its

own ethanol – the State Line Farm in Shaftsbury grows sweet sorghum to make ethanol (Tepping 2008). No ethanol is produced in the rest of Vermont, making it extremely impractical for ACTR.

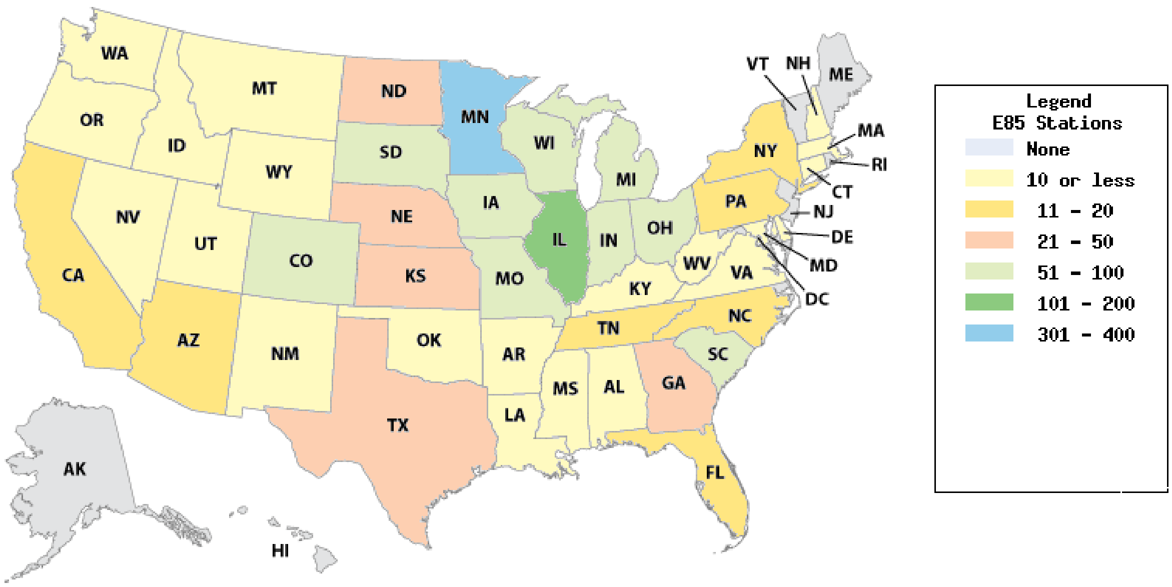

Figure 6. Map of ethanol fueling stations in the United States (United States Department of Energy 2008).

Biorefinery technology for cellulosic ethanol is currently being developed. Worldwide, there are nine demonstration plants capable of producing 3 million gallons of cellulosic ethanol per year (Childs and Bradley 2007). Around 20 facilities are being developed, and the United States Department of Energy announced on April 18, 2008 that it will invest $86 million over the next four years in three new cellulosic biorefineries, in addition to the six it is already funding (Biello 2008).

According to Netaka White, Biofuels Director at the Vermont Sustainable Jobs Fund, cellulosic ethanol has potential in Vermont, though the small amount of land

available in the state is a limiting factor. Feasible fuel sources include wood cellulose, agricultural waste crops, biomass, and switchgrass, for which there are currently trials underway in Vermont (White personal communication 2008).

Costs

A gallon of E85 yields 37% fewer miles than a gallon of gasoline because of its lower energy content (United States Department of Energy 2008). Though price per mile depends on the vehicle's efficiency, as of May 15, 2008, national average E85 prices were $4.33 per gasoline gallon equivalent (GGE), while gasoline averaged $3.77 (Oil Price Information Service 2008). Regular petroleum buses can run on an E10 blend (10% ethanol, 90% petroleum) without any modifications. Flex-fuel buses (currently used primarily in Sweden) run on E85 and cost between $17,000 and $34,000 more than diesel buses.

Emissions

Tailpipe Emissions

Ethanol has a high oxygen content (35%), which makes it burn more completely than gasoline. E10 reduces CO emissions by 10-30% per mile, depending on the combustion technology (Renewable Fuels Association 2005). SO_x emissions are reduced 39-43% per mile and PM is reduced by 50%, but NO_x emissions are doubled (Wu et al. 2006, Renewable Fuels Association 2005).

Life Cycle Analysis

Ethanol

Although tailpipe emissions for ethanol are lower than gasoline, total life cycle emissions of all of these air pollutants are increased, especially when considering higher blends such as E85 (Hill et al. 2006). Although life cycle analyses consider many factors, most leave out the effect of land use change. When land is cleared to grow crops for biofuels, not only is carbon emitted from the clearing of the land, but the carbon sequestration ability of the planted crop is much less than that of the original land cover, whether it be rainforest or grassland, which means less CO_2 is absorbed.

Figure 7 compares the GHGs produced in each step of ethanol and gasoline production and use. The figure shows that the production of ethanol is more energy-intensive than that of gasoline, the combustion emissions are slightly less than gasoline, and the feedstock does sequester CO_2. However, land use change inputs such high emissions into the equation that overall, corn ethanol produces 93% more GHGs than gasoline.

				Net land-use effects			
Source of fuel	Making feedstock	Refining fuel	Vehicle operation (burning fuel)	Feedstock carbon uptake from atmosphere (GREET)	Land-use change	Total GHGs	% Change in net GHGs versus gasoline
Gasoline	+4	+15	+72	0	–	+92	–
Corn ethanol (GREET)	+24	+40	+71	−62	–	+74 +135 without feedstock credit	−20% +47% without feedstock credit
Corn ethanol plus land use change	+24	+40	+71	−62	+104	+177	+93%

Figure 7. GHGs emitted by each step of gasoline and ethanol production and consumption. Units are in CO_2e per MJ (Searchinger et al. 2008).

Future Outlook

Biofuels were originally seen as the "silver bullet of climate change" – the solution for countries trying to reduce GHG emissions or struggling to deal with the rising cost of oil (Rosenthal 2008). Now it is clear that the land use changes needed to grow crops for biofuels will produce more CO_2 than the biofuels are saving. Many governments, including Australia, Britain, France, Germany, the Netherlands, Switzerland, and parts of Canada, have begun reducing or revising subsidies for biofuels (Leahy 2008). Despite the heavy subsidies for corn, United States politicians have begun to realize the problem biofuels are creating: 24 Republican senators led by John McCain recently called for the EPA to waive or restructure the rules that require an increase in ethanol production (Associated Press 2008).According to Searchinger et al. (2008), an effective system should guarantee that the biofuel uses waste products instead of food crops or carbon-poor lands that would not trigger large emissions from land use change.

Recommendations

Even if corn ethanol becomes available in Vermont, ACTR should not utilize the fuel because of the severe social and environmental costs. Cellulosic technology may eventually become available, and there are crops that could be utilized in Vermont. When the technology becomes available, ACTR could pursue a local source of cellulosic ethanol, although this would require a significant investment in infrastructure if the fuel were to be used in blends higher than E10.

Fuel Costs: Compressed natural gas (CNG) has historically cost less than diesel; however, increased supply and demand will continue to drive the price upward. If CNG were delivered at minimal cost to the Middlebury area via truck, its price per gasoline gallon equivalent (GGE) would most likely be less than the price per GGE of diesel.

Bus Costs: On average, buses cost $45,000 more than standard diesel buses. These costs may decrease in the future if demand for CNG vehicles increases. To absorb these costs, ACTR could pursue federal and state incentives and subsidies provided by the Energy Act of 1992 and other recent legislation for alternative fuel vehicles (AFVs).

Maintenance: Operation and maintenance of vehicles requires a well-trained staff. Staff training programs are encouraged as the maintenance schedules and engine problems differ from those of traditional diesel buses. ACTR would need to be dedicated to such a training program to successfully transition its fleet to CNG. The incremental costs of this action may not justify the use of CNG.

Infrastructure: No natural gas distribution and pipeline network exists in Vermont. Also, storage facilities and a fast-fill pump station would be very costly. To develop such infrastructure, ACTR would need to collaborate with local and regional public and private interests. Unless ACTR is willing to drive to Burlington to refuel or pursue funds from federal and local institutions, CNG vehicles will be difficult to implement.

Environment: The environmental benefits of CNG technology are numerous. They include near-zero emissions of SO_x and particulate matter (PM), approximately 50% less NO_x emissions, and 25% less CO_2 emissions than diesel. Also, CNG minimizes noise pollution and emits no noxious fumes. However, life cycle analyses (LCAs) show that greenhouse gas (GHG) emissions are relatively equivalent to those of diesel fuel.

Future Outlook: Contingent on proper infrastructure developed in Vermont, CNG buses will continue to decrease in cost, providing an attractive option for ACTR. CNG is also a forerunner to hydrogen as hydrogen will likely utilize similar infrastructure as CNG.

Recommendations: If the proper transmission and distribution infrastructure develops in Vermont, acquiring the funds to establish a CNG refueling station becomes more feasible. Under this circumstance, ACTR should reconsider CNG as an appropriate fuel, especially as a transition to hydrogen technology.

Compressed Natural Gas

Background

Compressed natural gas (CNG) is a clean-burning alternative to gasoline and diesel and is composed primarily of methane (CH_4) with smaller portions of ethane, butane, propane, nitrogen, helium, carbon dioxide, and hydrogen sulfide. At room temperatures it exists in gaseous form, and can be transported in either gaseous or compressed liquid form. Currently, natural gas accounts for a third of United States total energy use, predominantly in residential and commercial heating systems and for generation of electric power. Due largely to its extensive use in home heating and electricity generation, national infrastructure for the transportation of the fuel is well developed. Despite this infrastructure, only 0.1% of natural gas is utilized for transportation. Currently, approximately 150,000 CNG vehicles are in operation in the United States with approximately 22% of all new bus orders utilizing CNG technology (EERE, 2004).

Practicality

Infrastructure

Acquiring a fast-fill station is crucial for operating a successful CNG program. While 1,500 refueling stations exist in the United States today, only one is currently operating in Vermont. Refueling station costs range from $2.5-3 million. To raise funds, many public transportation authorities collaborate with local, state, and federal private and public institutions. For example, Vermont's one high-pressured fast-fill refueling station in Burlington was spearheaded by Senator Patrick Leahy who helped allocate $2 million from the Federal Transit Administration for the construction of the project (Big

Boost 2007). The station is used by Burlington's public transportation system, UVM's transportation fleet, and other heavy-duty state and city vehicles.

Besides refueling stations, CNG infrastructure is far from being operationally feasible in Middlebury. First, Vermont has only one natural gas distributor, Vermont Gas Systems, Inc., which exclusively serves Chittenden and Williston counties. The natural gas flows through pipelines in Canada and into Vermont Gas' pipeline at the Vermont/Canada border. Further distribution lines connect Vermont Gas to Chittenden and Williston counties, but do not extend into the rest of Vermont. To create an effective CNG refueling station, CNG infrastructure must be developed from the ground up, which would add considerable costs. This might not be possible without significant outside investment and collaboration with state, federal and private institutions.

Infrastructure represents the largest obstacle for a successful CNG program. To overcome this obstacle, ACTR would need to commit fully to CNG both now and in the future. ACTR would need to develop numerous partnerships and allocate human and financial capital to facilitate the construction of a CNG refueling station. Because of ACTR's limited funds and available staff time, this may not even be feasible.

Natural gas vehicles (NGVs) can be run either solely on CNG or liquid natural gas (LNG), or in combination with other fuels such as diesel, biodiesel, ethanol, fuel-cells, electric batteries, or gasoline. CNG and LNG systems operate similarly to conventional spark-lighted engines. There are currently three types of engines: bi-fuel, which runs on either diesel or CNG; dual-fuel, which can switch between diesel and CNG; and dedicated fuel, which uses only CNG. The methane and other light hydrocarbon gases are stored in high-pressure tanks within the vehicle. CNG engines,

however, are less fuel-efficient than gasoline and diesel engines and on average only cover up to two-thirds the distance of diesel vehicles per fill up. This is a result of CNG's lower energy content and the fuel storage limitations on vehicles (Kojima 2004).

Operation and maintenance costs can be high for CNG vehicles. Many operators of CNG fleets report that operation and maintenance costs are higher than those of traditional diesel buses due to more frequent breakdowns, less mileage per tank (increasing fuel costs) and a lack of maintenance expertise. Operators of successful CNG fleets have invested heavily in training personnel and local mechanics (Eudy 2004). Proper training programs are essential for a successful CNG fleet. This may be a difficult obstacle to overcome for acquiring CNG vehicles in Middlebury; however, facilitating relationships with maintenance personnel in the Burlington program may help solve this problem.

Finally, another major obstacle regarding CNG vehicles is price premium of CNG vehicles over diesel. On average, CNG buses cost $45,000 more than diesel buses, depending on the numbers of vehicles purchased (Eudy 2004). Heavy-duty vehicle producers state that increased usage of CNG vehicles will result in economies of scale, eventually lowering the price. On the other hand, extensive subsidies by federal and state governments help offset this incremental cost. It is crucial that ACTR tap into these incentive programs to help reduce costs if this technology is chosen.

Emissions

Natural gas is often seen as an environmentally-friendly fossil fuel alternative to gasoline, diesel, and even biodiesel. In a study conducted by the Department of Energy's

FreedomCAR and Vehicle Technologies program (FCVT), emissions from CNG were 53%, 85%, and 89% lower for NO_x, PM, and CO respectively, compared with traditional diesel heavy-duty transit buses (Figure 8) (EERE 2003).

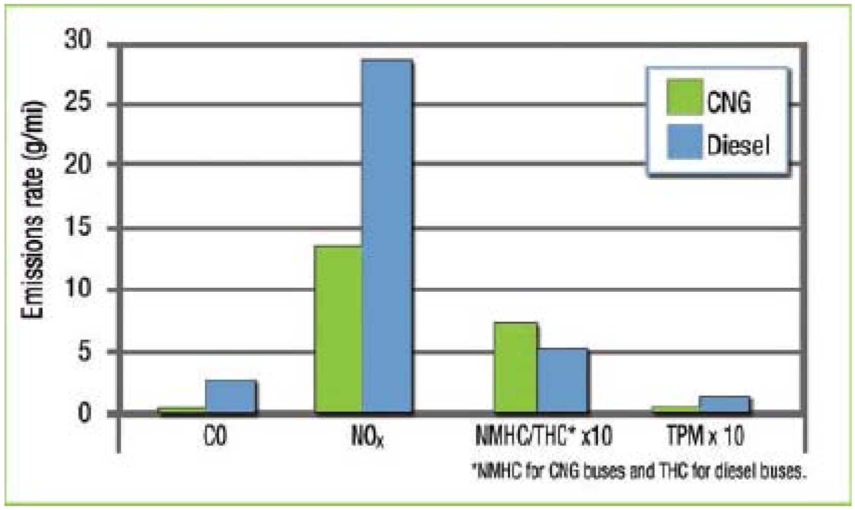

Figure 8. Natural gas emissions (g/mi) compared to traditional diesel (EERE 2007).

However, evidence about total reductions from CNG buses relative to diesel is inconsistent among studies. Recent studies conducted by the California Air Resources Board (CARB) and the University of California show that CNG offers emission reductions in CO_2, NO_x, and elemental carbon relative to diesel buses equipped with particulate filters and oxidation catalysts. The difference in nitrous oxides is significant at around 50%, while carbon dioxide reductions are around 25%.

On the other hand, CNG buses, even with oxidization catalysts, emitted 10.4 g/mile of methane gas (methane is 23 times more potent than CO_2 as a GHG) while diesel buses emitted zero methane (Ayala 2003). In a full LCA of CNG vehicles, it is shown that when natural gas is domestically produced, life cycle GHG emissions of CNG are approximately equal to those of diesel, each emitting around 400 g/mi of CO_2e. For

natural gas imported from abroad, the life cycle GHG footprint is larger for CNG than it is for diesel (Argonne 2005). In summary, the greatest environmental benefits derived from CNG technology are achieved through reductions in NO_x. Of other major environmental pollutants, technological fixes allow many diesel heavy-duty vehicles to achieve similar emission reductions to CNG technology.

Costs

In the United States, CNG usually costs less than gasoline or diesel in terms of energy equivalents. Although it is largely a domestically-produced fuel, 16.6% of total natural gas consumed in 2007 was imported, and this number continues to rise (EIA 2007). The price of natural gas continues to rise because it is increasingly used as a substitute for coal in electricity generation.

Despite this supply constraint, CNG prices per GGE still remain below that of diesel in New England. In 2007 and 2008, the price of diesel has skyrocketed, currently reaching over $4.50 per gallon. Comparatively, New England prices of CNG have remained relatively steady at $2.33 per GGE (DOE 2008). However, the price of natural gas is influenced by the same volatility as gasoline and the prices of the two are highly linked. One major benefit of CNG is that it does not experience the same supply constraints from increased use in China and India as gasoline does, which will guarantee lower prices of CNG in the future. However, the rising natural gas prices as well as infrastructural obstacles in New England could lead to price increases in the future.

Future Outlook

Looking forward, CNG vehicles will continue to improve. Some CNG vehicles in certain transit fleets combine CNG with hydrogen fuels. This technology is known as hydrogen/compressed natural gas (H/CNG) and is seen as a progressive step towards the "hydrogen fuel economy" envisioned by the current administration. Simple alterations to a CNG engine will allow heavy-duty vehicles to use a hydrogen blend. While this technology is still not cost-effective, continued investment in this technology may create an extremely clean-burning, operationally-efficient vehicle in the near future. Familiarity and investment in first-generation CNG vehicles will help the transition to second-generation fuels by establishing the proper infrastructure and mechanical expertise needed to operate a successful CNG fleet.

Fuel Costs: For hydrogen (H_2) to be considered a truly clean fuel it must be produced using renewable energy sources like wind. The cost of hydrogen depends on the method of production, but has averaged \$4.46/kg of H_2 or gasoline gallon equivalent (GGE) for hydrogen produced from steam methane reforming. Fuel efficiency ranges from 3.52 mi/DGE to 8.33 mi/DGE, depending on the type of drive train technology.

Bus Costs: Full-sized transit buses are currently prohibitively expensive (i.e., \$2-\$3 million). Prices are expected to decrease as the technology develops and mass production begins.

Maintenance: Reported maintenance costs of fuel cell transit bus demonstrations have averaged \$0.46/mi for a fuel cell bus with a hybrid electric drive system and \$0.58/mi for hydrogen hybrid internal combustion engine (HHICE) buses.

Infrastructure: Hydrogen fuel cells have proven successful in a range of vehicle sizes, from personal automobiles to 22- and 40-foot transit buses. Hundreds of transit bus demonstrations are successfully operating globally, in climates ranging from hot, dry Southern California to wintry Manitoba, Canada. There is only one hydrogen fueling station in Vermont (located in Burlington) and 31 across the United States, 24 of which are in California. Fueling stations and maintenance facilities are currently very expensive, and several design problems need to be resolved.

Environment: The only tailpipe emission from a hydrogen fuel cell is water vapor. GHGs are associated with hydrogen production for certain methods, and with infrastructure development.

Future Outlook: Hydrogen fuel cells are not expected to hit the commercial, mass-produced marked for 10 to 15 years. Fuel cell transit buses may be available sooner because buses have traditionally been a tool for demonstration and testing.

Recommendations: Prices are currently far too expensive to be a near-term realistic goal for ACTR, but the technology may serve as a long-term goal.

Hydrogen Fuel Cells

Background

The current presidential administration has called hydrogen “the ultimate clean energy carrier” and supports the transition to a hydrogen economy with its Fuel Initiative (White House Press Release 2003). It is widely accepted that a pollution-free, hydrogen-based energy system is a worthy goal, but there are great challenges to making hydrogen a truly “clean” energy, namely, that renewable energy must be used in hydrogen production, which will require substantial capital investment for conversion to a renewable energy infrastructure. This makes the focused goal of creating a hydrogen infrastructure into a much larger goal of changing the nation’s entire technological and economic basis, leaving even the most technologically-savvy environmentalists asking the question, “how do we get there?” (Griscom 2003).

Hydrogen fuel cell research, development and testing are predicted to continue for at least another decade. Large-scale commercialization and mass-production of the technology are not expected to occur before 2015 (Helmolt 2007). There are several obstacles to overcome in order to make hydrogen fuel cells competitive with the current range, power, and costs of conventional fuel technologies. These challenges include the need to reduce costs, reduce the size of the fuel cell stack and increase its power density, reduce overall weight of the fuel cell and electric propulsion system, optimize electric motors and control systems for heavy-duty use, increase durability, and develop a hydrogen infrastructure for vehicle use (Chandler 2007).

Sourcing

Hydrogen is the simplest element and most plentiful gas in the universe, but it rarely exists by itself; instead, it quickly combines with other elements such as oxygen and carbon. Therefore, hydrogen must be derived from other substances, which can be done in a number of ways resulting in a range of economic viability and environmental sustainability.

Natural Gas Reforming and Methane Partial Oxidation

Steam methane reforming followed by methane partial oxidation is the most common method for producing the United States, accounting for about 95% of the nation's hydrogen production. The disadvantages of this method are that natural gas supply is ultimately limited, and they provide only a "modest reduction" in vehicle emissions as compared to hybrid vehicles (Turner 2004). Producing hydrogen from natural gas is not seen as a long-term solution.

Coal and Biomass Gasification

Both biomass and coal can be used to produce hydrogen through a series of chemical reactions. Hydrogen production via coal gasification is more efficient and cheaper than hydrogen production via coal-powered electrolysis (Turner 2004). Carbon capture and sequestration (CCS) technologies may allow hydrogen to be produced directly from coal with "near-zero greenhouse gas emissions" (United States Department of Energy). However, this method is not a recommended solution because it reinforces unsustainable dependence on non-renewable fossil fuels.

Biomass gasification to produce hydrogen also releases "near-zero net greenhouse gases" because biomass sequesters carbon dioxide as a part of its natural processes

(United States Department of Energy). However, it is estimated that biomass cannot supply the amount of hydrogen that would be required (Turner 2004).

Electrolysis

Electrolysis uses an electric current to split water molecules into hydrogen and oxygen. The “clean” status of electrolysis is dependent upon using a clean, renewable electricity source like wind. Electrolysis requires a great amount of energy input and is currently expensive. The efficiency of the electrolysis process may be improved in the future by using solar heat or heat from a nuclear reactor to increase the water temperature.

Photobiological

There is potential to capture the hydrogen naturally produced by microbes, such as green algae and cyanobacteria, as a byproduct of their metabolic processes when they consume water in the presence of sunlight. This method is in the early stages of research and development and is far from becoming commercially viable (United States Department of Energy).

Practicality

Infrastructure

Hydrogen infrastructure and distribution are in the experimental phase of development, but offer potential because they are adaptable to both rural and urban environments. Hydrogen can be produced as far as several hundred miles away at large central plants as well as at local refueling stations or stationary power sites in small distributed units. However, the transition to a hydrogen economy will require a

substantial capital investment and time commitment in the maintenance and production facilities, as well as in the hydrogen transport and delivery infrastructure (United States Department of Energy 2008). There is a general lack of standards, choice, information and quantity for both infrastructure and buses (Chandler Sept 2007). Common challenges encountered with infrastructure design include the inefficient sizing of fueling stations, malfunctions of hydrogen safety sensors for tank leaks, maintenance issues, availability of replacement parts and the fact that changing technologies quickly become obsolete. Another drawback is that the refueling process for a bus typically takes between 10 and 20 minutes for a full fill at a rate of approximately 2 kilograms per minute, with one kilogram of hydrogen having comparable energy output to one gallon of gasoline (Chandler Sept 2007).

Fuel cell integration into a range in vehicle sizes from personal automobiles to 40-ft. transit buses has demonstrated the scalability of the fuel cell system. Since 1994, there have been at least 25 fuel cell demonstrations worldwide in climates ranging from southern California to Manitoba, Canada, with varying fleet size and technologies. Hydrogen fuel cells have recently proven successful in 22-foot, 22-passenger buses with hybrid electric drive trains at the University of Delaware and the University of Texas at Austin. Theses buses have twin high-pressure tanks in the roof to store 16 kilograms of hydrogen, giving an estimated range of 200 miles (Thomas and Mbuga 2007).

The integration of fuel cells into vehicles is similar to the integration of standard internal combustion engines (ICE) in terms of mechanics and sizing. Mass production can therefore likely occur on the basis of existing car platforms, allowing simple and cost-efficient vehicle assembly in existing manufacturing facilities (Helmolt 2007).

Design challenges included the added height of up to two feet on fuel cell buses because of hydrogen storage on the roof as well as the additional bus weight of up to 8,000 lbs. as compared to a diesel bus (Chandler 2007). Fuel cell transit bus demonstrations have reported that finding quality bus parts and gaining access to maintenance information quickly has been a challenge (Chandler 2007). Performance data information is also scarce or incomplete because manufacturers want to protect intellectual property and competitive marketing position. This also makes it difficult for demonstrations to project an accurate budget (Chandler 2007).

Mechanics

There are both mechanical advantages as well as challenges associated with a hydrogen economy. Durability and chemical degradation of the fuel cell are pressing concerns (Helmolt 2007), but the University of Wisconsin-Madison and University of Maryland have recently made significant progress in the reliability of the fuel cell. These developments will play an important role in the speed at which hydrogen fuel cell vehicles become available on the mass market (Beal 2008).

Feedback from fuel cell bus demonstrations in the United States has been largely positive. Fuel cell buses in the United States have performed similarly to, or better than, conventional buses, performing well under all conditions, operating on bus routes with varying speeds, terrain, traffic conditions, and climates. The fuel cell buses have proven to have smooth, fast acceleration and much quieter propulsion systems than their diesel and CNG counterparts (Chandler Sept 2007).

Availability

Currently, there are only 31 hydrogen stations across the country, 24 of which are in California. There is only one private-access-only hydrogen fueling station in Vermont, located in Burlington at the Department of Public Works. The number of hydrogen fuelling stations should grow in the next few years as transit bus demonstrations increase and as General Motors and Honda implement their plans to lease hydrogen fuel cell cars (Rogers 2008). However, GM stressed that the refueling infrastructure needs to be built before the company can begin widespread leasing hydrogen fuel cell vehicles (Rogers 2008).

Costs

Infrastructure, vehicles, fuel, and maintenance costs associated with hydrogen fuel cells are currently prohibitively expensive. For hydrogen demonstrations, the cost of facilities has ranged from several hundred thousand dollars up to $4.4 million for a maintenance facility, fueling station, and bus wash (Chandler Sept 2007). Hydrogen fuel cell transit buses are currently $2 to $3 million. Projections show that fuel cell vehicles can be produced at an affordable cost if produced in high enough volumes, i.e., over 1 million (Helmolt 2007). The hydrogen fuel itself is also currently very expensive. Costs range depending on the method of hydrogen production, with coal gasification and natural gas reforming being the cheapest. SunLine Transit Authority in Thousand Palms, California reports hydrogen produced with the new HyRadix natural gas reformer costs $4.26 per kg of hydrogen or gasoline gallon equivalent (GGE) (Chandler Oct 2007). In order to produce hydrogen at a competitive price, large quantity production must be

developed while minimizing distribution and transportation costs. Cost reduction goals set by the DOE have been repeatedly raised and postponed, eroding public confidence in the stated timelines. Fuel cell demonstrations have reported maintenance costs of \$0.46 per mile for a fuel cell bus with a hybrid electric drive system and \$0.58 per mile for a HHICE bus (Chandler 2006).

Emissions – Life Cycle Analysis

The challenges in completing a comprehensive LCA of hydrogen fuel cells include uncertain, varying, or unavailable data, changing technologies, assessing the many possible fuel pathways, and the ambiguity in where to draw the boundary for the analysis (Schindler 2003). Tracking the amount of hydrogen fuel production and actual cost of the fuel has proven difficult because manufacturers are hesitant to release data in order to protect their competitive advantage (Chandler 2007). It is useful express the LCA figures in kg CO2e/kg H_2 because the energy content of one kg of hydrogen closely compares to one gallon of gasoline (Table 2).

Life Cycle Emissions of Hydrogen from Liquid Natural Gas

The National Energy Technology Laboratory (Ruether et al. 2005) LCA accounts for the hydrogen production, processing, liquefaction, ocean transport, regasification, pipeline transport of natural gas, and steam methane reforming with and without carbon capture and sequestration (CCS) processes. The National Renewable Energy Laboratory (Spath and Mann 2001) estimates a higher LCA by adding the construction and decommission of the infrastructure, the natural gas production, electricity generation, and plant operations (Table 2). Both of the reports estimated the life cycle emissions of H_2

produced from LNG without CCS to be greater than that of gasoline and every other production method of H_2, with the exception of H_2 produced from underground mined-coal without CCS or CMM methods. However, the life cycle CO_2 equivalent emissions associated with H_2 produced from LNG with CCS is approximately half that of gasoline. Reduction in hydrogen plant energy efficiency and changes in natural gas losses both significantly alter the calculated life cycle emissions and life cycle energy efficiency (Spath and Mann 2001). Sensitivity in the calculations from pipeline transportation distance for hydrogen is minimal (Ruether et al 2005).

Life Cycle Emissions of Hydrogen from Coal

The LCA of hydrogen from coal takes into account coal mining, rail transport of coal, and conversion of coal to hydrogen, from underground mined coal with and without CMM and CCS, and from surface mined coal with CCS (Table 2). The LCA of H_2 produced from underground mined-coal without CCS or CMM methods is around 50% greater than that of gasoline, whereas the LCA of H_2 produced from underground mined-coal with CMM and 92% CCS is about one-fourth that of gasoline. Sensitivity in the calculations due to uncertainty in the coal mine methane emissions has little effect on total GHG emissions, because the majority is emitted during operation (Ruether et al 2005).

LCA of Hydrogen via Wind-Powered Electrolysis

Although hydrogen produced by electrolysis is not usually powered by renewable wind energy, it is the cleanest, most sustainable option for hydrogen production. Life cycle carbon dioxide equivalent emissions from one kilogram of hydrogen (which has roughly the same energy capacity as one gallon of gasoline) produced via wind-powered

electrolysis, are over nine times less than burning one gallon of gasoline (Table 2). The LCA of hydrogen production via wind-powered electrolysis considers the iron used in turbine manufacturing and hydrogen storage vessels, the limestone used primarily for the turbines' concrete foundations, the coal consumed in production of the iron, steel, and concrete for turbine construction, the oil and natural gas used in turbine manufacturing, and the water consumed in the both the electrolysis and upstream processes (Spath and Mann 2004).

Table 2. Life Cycle GHG emissions of various H_2 production methods.

H_2 Production Methods	**Life Cycle GHG Emissions (CO2e/kg H_2 or gge)**
Baseline: Burning one gal. gasoline	8.8
H_2 from LNG without CCS	8.9 (Ruether et al 2005); 11.88 (Spath and Mann 2001)
H_2 from LNG with CCS	4.47 (Ruether et al 2005)
H_2 from underground mined Coal with no CMM or CCS	12.4 (Ruether et al 2005)
H_2 from underground mined Coal with CMM and 92% CSS	2.1 (Ruether et al 2005)
H_2 from Electrolysis/Wind	0.97 (Spath and Mann 2004)

The availability of water should not be a concern in the life cycle analysis of electrolysis. The seemingly large amount of water needed for hydrogen production – 26.7 liters of water per kilogram of hydrogen (Spath and Mann 2004) and 100 billion gallons of water per year to produce enough hydrogen to fuel the 230 million vehicles in the United States "light duty fleet"— is actually minimal in comparison to the 300 billion gallons of water used annually by the United States for the production of gasoline (Turner). As hydrogen use increases and gasoline use decreases, the consumption of water for gasoline production can transition over to hydrogen production. Water use and life cycle emissions may significantly improve in the future, after wind infrastructure is in place, due to the fact that the majority of current water and energy usages are associated with manufacturing of wind turbines and hydrogen storage vessels. The life cycle

emissions may also be lowered when site specific soil conditions allow less concrete and steel to be used in the wind turbine foundation.

Efficiency

The net energy efficiency ratio equates to the MJ of H_2 produced for every MJ of energy put into the production process. Hydrogen via wind-powered electrolysis has the greatest net energy efficiency by far (Table 3).

Table 3. Energy Efficiency of various H_2 production methods.

	Net Energy Efficiency (output MJ/input MJ)
Baseline: Burning one gal. gasoline	
H_2 from LNG without CCS	0.66 (Spath and Mann 2001)
H_2 from LNG with CCS	0.66 (Spath and Mann 2001)
H_2 from underground mined Coal with no CMM or CCS	Data Not Available
H_2 from underground mined Coal with CMM and 92% CSS	Data Not Available
H_2 from Electrolysis/Wind	13.2 (Spath and Mann 2004)

Studies show that hydrogen FCVs and hydrogen FCV HEVs also have far better fuel economies than baseline gasoline technologies and all other alternative fuel vehicles (Brinkman et al 2005). Fuel economy observed by United States fuel cell transit bus demonstrations has ranged from 3.52 miles per diesel gallon equivalent (DGE) for fuel cell transit buses without hybrid configuration, to 4.96 mi/DGE for an HHICE bus, to 8.33 miles per DGE for fuel cell transit buses with hybrid configuration (Chandler Sept and Oct 2007). The latter number is over 2 times higher than the baseline comparison of a diesel transit bus getting 4 miles per diesel gallon (Chandler Sept 2007).

Future Outlook

Hydrogen fuel cells are widely considered the best overall long-term solution, but significant technical improvements are necessary (Helmolt 2007). Inconsistent public policy, with disjointed mandates and incentives, and constant shifting of priorities and support from one alternative fuel technology to another has hindered the overall transition to alternative fuels (Mendelez 2007). Large-scale commercialization and mass-production of hydrogen fuel cells are unlikely to occur before 2015 (Helmolt 2007). Fuel cell technology is likely to enter the commercial market in transit buses before automobiles, due to the fact that fuel cell technologies have been developed for a number of transit bus demonstration projects. This could work to the advantage of ACTR, especially in light of the recent success of fuel cell demonstrations on 22-foot buses at the University of Delaware and the University if Texas. Although hydrogen fuel cells will help the United States eliminate oil use, they are unlikely to reach mass commercialization in the next decade.

Recommendations

While a possible transition to hydrogen slowly occurs, hybrids should be implemented as a near-term solution, so that progress towards eliminating emissions and addressing global warming can begin immediately. Because hybrids share much of the same technology as hydrogen fuel cell vehicles, improving hybrid technology and mass commercialization of hybrid vehicles will directly affect the timeline and cost of hydrogen fuel cell vehicles. Hydrogen fuel cell vehicles may serve as a long-term goal as infrastructure develops nationally and locally, and vehicles become less expensive.

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Appendix A Hybrid Links

Hybrid Electric Bus Market Websites:

BAE Product

Information regarding BAE's hybrid propulsion system:
http://www.baesystems.com/BAEProd/groups/public/documents/content_image/bae_pdf_eis_busdatasheet.pdf

General Motors Product

Information regarding GMP's hybrid propulsion system:
http://www.gm.com/corporate/responsibility/reports/05/400_products/3_thirty/431.html.2005

ISE Product

Information regarding ISE's hybrid propulsion system:
http://www.isecorp.com/ise_products_services/diesel_hybrid_drive_system/
Information regarding ISE company policy and current customers:
http://www.isecorp.com/ise_company_info/about_ise/

New Flyer of America, Inc.

Information regarding hybrid electric buses sold by New Flyer:
http://www.newflyer.com/index/hybrid_buses_intro

Funding Programs:

Clean Fuels Grant Program –
"The Clean Fuels Grant Program assists designated ozone and carbon monoxide air quality non-attainment and maintenance areas in achieving or maintaining the National Ambient Air Quality Standards through grant funding. The program accelerates the deployment of advanced bus technologies by supporting the use of low-emission vehicles in transit fleets. The program assists transit agencies in purchasing low-emission buses and related equipment, constructing alternative fuel stations, modifying garage facilities to accommodate clean fuel vehicles, and assisting with the use of biodiesel. For more information, see the Clean Fuels Grant Program fact sheet. (Reference 49 U.S. Code 5308, and 49 CFR 624)" (http://www.eere.energy.gov/afdc/progs/view_ind_fed.cgi?afdc/309/0).

Federal Transit Administration –
"A major way FTA helps communities support public transportation is by issuing grants to eligible recipients for planning, vehicle purchases, facility construction, operations, and other purposes… Generally, FTA funds are available to designated recipients that must be public bodies (i.e. states, cities, towns, regional governments, transit authorities, etc.) with the legal authority to receive and dispense federal funds… Financing the construction, operation and maintenance of public transportation systems involves many different types of funding sources, including Federal and non Federal grants, loans, and revenue sources. The Federal Transit Administration participates in USDOT sponsored credit assistance programs, including the TIFIA (The Transportation Infrastructure Finance and Innovation Act) program and the State Infrastructure Bank program. These programs offer additional non-grant funding flexibility for transportation projects including direct loans, loan guarantees, lines of credit, and credit enhancement support such as bond insurance" (http://www.fta.dot.gov/grants_financing.html).